New Measurement of σ_{tot} in Proton-Proton Scattering in Pure Spin States*

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We have remeasured the total cross section for proton-proton scattering at 2–6 GeV/c in the spin states $\uparrow\uparrow$ and $\uparrow\downarrow$ perpendicular to the beam direction. With the reduced errors significant differences were found between the two cross sections.

During the first run with the Argonne National Laboratory zero-gradient-synchrotron polarized proton beam, our group measured[1] the spin dependence of σ_{tot} for pp scattering at 3.5 GeV/c. The run was quite short and the error was ± 2 mb, which only gave an upper limit on the spin dependence. We recently had a longer run with various improvements which reduced the total error by up to a factor of 30. This allowed us to see clear differences between $\sigma_{tot}(\uparrow\uparrow)$ and $\sigma_{tot}(\uparrow\downarrow)$.

The σ_{tot} measurement was a standard "good geometry" attenuation experiment using the same scintillation-counter detectors described in Fig. 1 of Ref. 1. We obtained the difference between the antiparallel and parallel total cross sections by using the equation

$$\sigma_{tot}(\uparrow\downarrow)-\sigma_{tot}(\uparrow\uparrow) = \frac{-\{[I(O)/I]_{\uparrow\downarrow}-[I(O)/I]_{\uparrow\uparrow}\}}{\langle I(O)/I\rangle N_0 \rho t P_B P_T}. \qquad (1)$$

The numerator contains the ratios of the transmitted event coincidences $I(O)$ to the number of incident protons I for the two different spin states which are perpendicular to the beam direction; and $\langle I(O)/I\rangle$ is the spin-average value of this ratio. N_0 is Avogadro's number 6.02×10^{23} while $\rho=0.073\pm0.005$ is the density of hydrogen protons in the polarized proton target and $t=4.13$ cm is the length of the polarized proton target. P_B and P_T are the beam polarization and target polarization which are $(70\pm5)\%$ and $(86\pm5)\%$. Because the beam and target were only partially polarized, because the target was only about 10% hydrogen, and because the target absorbed only about 10% of the beam, we needed very high precision in the measurement of the differences between the $I(O)/I$ ratios to obtain a good measurement of $\Delta\sigma_{tot}\equiv\sigma_{tot}(\uparrow\downarrow)-\sigma_{tot}(\uparrow\uparrow)$. To obtain a precision of about ±0.07 mb in $\Delta\sigma_{tot}$ at 6 GeV/c required a precision of about $\pm4\times10^{-6}$ in the difference between the $I(O)/I$ ratios.

There were three major improvements over our earlier experiment that allowed us to obtain this precision.

(1) The logic electronics, the photomultiplier-tube supplies, and the spill length were modified to allow us to increase the beam intensity from 2×10^4/pulse to 2×10^5/pulse without significantly increasing the counting losses or accidentals. We also took data for about 10 times longer. Thus, we had at least 100 times more events (3×10^{10} at 6 GeV/c), reducing the statistical error by more than a factor of 10.

(2) The beam polarization p_B increased slightly from 62% to 70%. The target polarization p_T was increased significantly from 30% to 86% by using the new ^{3}He-cryostat polarized proton target PPT V. This is a copy of a CERN cryostat and is described in our recent paper.[2] Thus P_BP_T increased from 0.186 to 0.602 for a gain of 3.24.

(3) The systematic errors benefitted from a modification to the polarized-ion source made by the zero-gradient-synchrotron staff[3] at the suggestion of one of the other experimental groups.[4] The rf transition stage was modified so that the spin of the beam protons was flipped on alternate

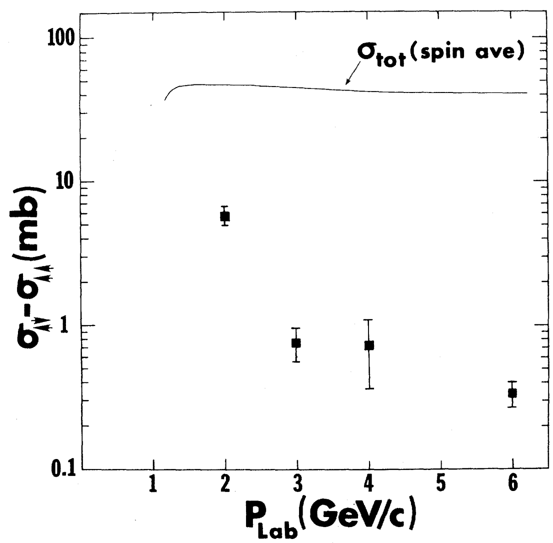

FIG. 1. The difference between the proton-proton total cross sections in the antiparallel and parallel spin states plotted against the incident beam momentum. The spins are measured perpendicular to the beam direction. The normal (spin-average) σ_{tot} taken from other experiments (Ref. 5) is also shown. The data are preliminary but the final values should fall within the quoted error bars.

pulses. This greatly improved the precision in measuring the difference between $\sigma_{\uparrow\downarrow}$ and $\sigma_{\uparrow\uparrow}$ by allowing us to signal average over any long-term (more than a few seconds) drifts in the position, size, intensity, or spill structure of the beam. We did further checks on systematic differences between beam ↑ and beam ↓ by periodically reversing the direction of the target spin approximately twice a day, and by using the relations from rotational invariance of space,

$$\sigma_{tot}(\uparrow\uparrow)=\sigma_{tot}(\downarrow\downarrow), \quad \sigma_{tot}(\downarrow\uparrow)=\sigma_{tot}(\uparrow\downarrow). \qquad (2)$$

The observed differences were considerably smaller than the effect and were removed by averaging.

The measured total cross sections are shown in Fig. 1 where the difference between $\sigma_{\uparrow\downarrow}$ and $\sigma_{\uparrow\uparrow}$ is plotted against p_{lab}; the spins are perpendicular to the beam. The difference is clearly nonzero and positive. Our earlier result[1] at 3.5 GeV/c of $\sigma_{\uparrow\downarrow}-\sigma_{\uparrow\uparrow}=-1.8\pm2.0$ mb, although of opposite sign, is still consistent with the new results (about 1.2 standard deviations away from the interpolated value of 0.6 from the new data). There are two somewhat surprising features of this data.

The antiparallel cross section $\sigma_{tot}(\uparrow\downarrow)$ is larger than the parallel cross section $\sigma_{tot}(\uparrow\uparrow)$. However, in elastic scattering C_{nn} is generally positive where it has been measured,[4,6] implying that $\sigma_{elas}(\uparrow\uparrow)$ may be larger than $\sigma_{elas}(\uparrow\downarrow)$. This clearly shows the need for measuring C_{nn} near $P_\perp{}^2=0$, for comparisons through the optical theorem.

Next, notice the very large value of $\sigma_{tot}(\uparrow\downarrow)-\sigma_{tot}(\uparrow\uparrow)$ of almost 6 mb at 2 GeV/c, much larger than the value at 3 GeV/c of 0.76 mb. We were unable to find any significant sources of error and concluded that this rapid change is real. The physical origins of this large difference are not understood by us.

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